Ioffe Institute
6th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 22–26, 1998.

SPM based real-time controlled assembly of predefined nanostructures for fabrication of lateral quantum devices

Lars Montelius, Sven-Bertil Carlsson, Tobias Junno, Martin Magnusson, Knut Deppert, Hongqi Xu and Lars Samuelson
Division of Solid State Physics & The Nanometer Structure Consortium, Lund University, P.O. Box 118, S-221 00 Lund, Sweden
e-mail: lars.montelius@ftf.lth.se

The dimensions of electronic devices have been reduced approximately a factor of two every three years for the last 20 years, effectively meaning an increase of capacity with a factor of four. This trend, known as Moore's law, is predicted to hold for the next decade as well, although small deviations are foreseen. This means that around year 2010 the linewidths of the components produced in large scale will be below Å 100 nm. This presents a great challenge not only to the technology community for fabricating these devices, but also to the electronic design people since the electronic properties of nm-scale devices will be governed by quantum mechanics.

Presently, there is a rapid growing interest in quantum devices based on single-electron-tunneling (SET)-effects. Such SET-devices are possible candidates for single electron memories that might allow room temperature operation. Coulomb blockade effects have been observed at low temperatures in numerous tunnel barrier structures for both metals and semiconductors. The first observation of Coulomb charging effects at room temperature was obtained by creating a vertical double barrier structure using the tip of a scanning tunneling microscope and a small metal particle. However, from a practical point of view it is obvious that scanning tunneling microscopes cannot form the basis for any electronics applications where single or complex combinations of SET devices will be used.

Lately the focus of possible room temperature SET-devices have instead been shifted towards fabrication of lateral tunnel structures. For instance, Chen *et al* deposited AuPd nanocrystals in-between Au electrodes defined by e-beam lithography, and they reported clear Coulomb blockade effects at 77 K. However, the fabrication method is very hard to control and reproduce, which limits it's practical use for making devices. Other techniques that might have a larger potential for device fabrication involves some kind of self-aligning/assembly process(es) of conducting particles between metal electrodes, as reported by Klein *et al.* They managed to make a link of several colloidal Au clusters between e-beam defined electrodes. The electrodes were chemically modified in order to achieve good adhesion of the colloidal particles. However, large fluctuations in the obtained I–V spectra due to environmental changes during the measurement makes also this method not optimal.

We have during the last 2–3 years developed a new way to build extremely small scale and accurate structures for contacting of nano-objects. The principle is based on the use of the atomic force microscope (AFM) for very accurate movement of pre-fabricated nano-objects, such as lift-off defined metal discs, aerosol fabricated nano-particles and colloidal gold particles. The assembly procedure consists of moving se-

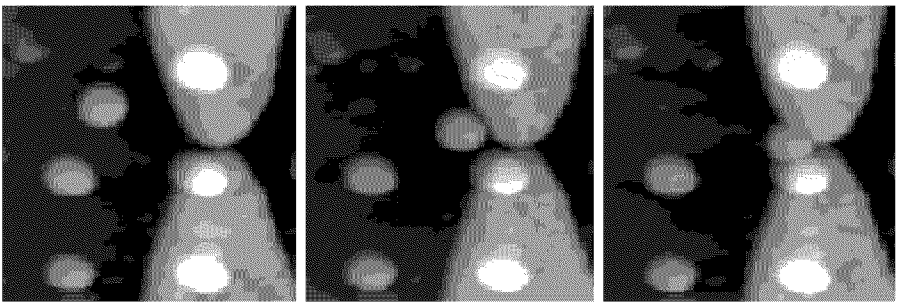

Fig 1. Three AFM images (740 nm × 740 nm) recorded during the manipulation of an Au disc into a gap between two Au electrode.

lected nanometer sized objects into a small gap between two metal electrodes (see Fig. 1).

The metal electrodes are defined by e-beam lithography using a conventional lift-off technique. The imaging and manipulation is done in ambient air condition using an ultra-sharp non-contact AFM tip. For imaging we used an oscillation frequency of around 170 kHz and lock-in detection of the amplitude change. The sample holder stage has been modified making electrical in-situ monitoring during the assembly procedure possible. The commercial relatively sharp AFM tips have been further processed by EBD (E-beam deposition), resulting in a carbon rich ultra sharp tip. Sometimes, the EBD tips have been further sharpened by putting the tips in an oxygen plasma, thereby thinning and sharpening resulting in a typical tip radius in the range of 10–20 nm.

The method for imaging and manipulation can be described as follows: make an image in non-contact mode, select the particle to be moved, position the tip slightly away from the particle, open the feed-back loop, advance the tip into contact with the particle, push the particle by the tip induced lateral forces to the desired position, withdraw the tip, establish feedback and acquire a new image displaying the outcome of the particle translation. One of the major advantages with our method is the possibility

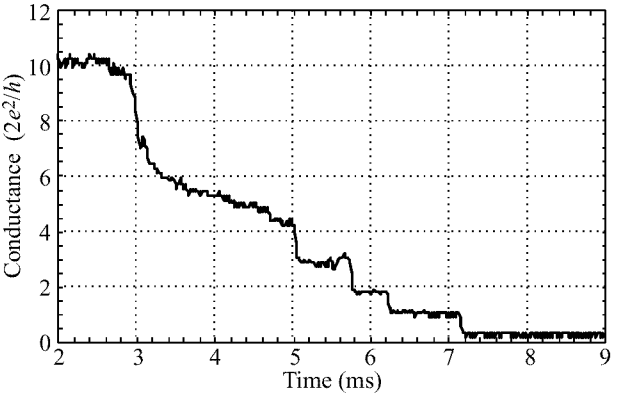

Fig 2. Dynamic behavior of the conductance as an Au nanodisc is being pushed out of contact with the electrodes. The applied bias voltage was 2 mV and the temperature 300 K.

to electrically monitor the assembly procedure by having a potential applied between the electrodes.

The techniques of pre-fabricating nm-scale building blocks and AFM-manipulation with simultaneous electrical measurements have for instance allowed us to build single-electron and quantum transport devices with control on the Ångström level. As examples of these results we show in Fig. 2 the experiment in which quantized point contacts (QPCs) are formed with control of the nano-wires in the range of some few Ångströms manifested in the conductivity plateaus in the units of $2e^2/h$.

Furthermore, by pushing the particles just small steps, nominally 1 Å, it is possible to stabilize the current at a certain conductance plateau level for timescales up to several 10's of minutes. In this condition, the current is stable and decoupled from environmental fluctuations since the mass of the particle is so tiny that gravitational forces are not in affect. This method of assembling structures using predefined nanosized object is to be seen as a versatile tool for nano-scale contacting and investigation of both inorganic and organic nano-objects, e.g. a particle covered with an organic "skin".

Acknowledgment

This work has been performed within the "Nanometer Structure Consortium" in Lund, and we gratefully acknowledge support from the Swedish National Board of Technical and Industrial Development, the Swedish Natural Science Research Council, the Swedish Technical Research Council, The Foundation of Strategic Research and the Crafoord Foundation.

References

The material presented above is based upon the following references:

T. A. Fulton and G. J. Dolan, *Phys. Rev. Lett.* **59** 109 (1987).

U. Meirav, M. A. Kastner, and S. J. Wind, *Phys. Rev. Lett.* **65** 771 (1990).

Hongqi Xu, *Phys. Rev. B* **48** 8878 (1993).

K. Nakazato, R. J. Blaike, and H. Ahmed, *J. Appl. Phys.* **75** 5123 (1994).

W. Chen, H. Ahmed and K. Nakazato, *Appl. Phys. Lett.* **66** 3383 (1995).

T. Junno, K. Deppert, L. Montelius and L. Samuelson, *Appl. Phys. Lett.* **66** 3627 (1995).

K. Deppert and L. Samuelson, *Appl. Phys. Lett.* **68** 1409 (1996).

D. L. Klein, P. L. McEuen, J. E. Bowen Katari, R. Roth and A. P. Alivisatos, *Appl. Phys. Lett.* **68** 2574 (1996).

K. Deppert, et al., *J. Crystal Growth* **169** 13 (1996).

L. Montelius, T. Junno, S.-B. Carlsson and L. Samuelson, *Microel. Engin.* **35** 281 (1997).

T. Junno, S.-B. Carlsson, H. Xu, L. Montelius and L. Samuelson, *APL* **72** 548 (1998).

S.-B. Carlsson, K. Deppert, T. Junno, M. H. Magnusson, L. Montelius and L. Samuelson, *Semicond. Sci. Technol.* in press (1998).